Increasing the Data Rate for Reflected Optical Camera Communication Using Uniform LED Light

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***Abstract*—*Optical Camera Communication* (OCC) systems relying on commercial-off-the-shelf (COTS) devices have attracted substantial attention recently, thanks to the pervasive deployment of indoor LED lighting infrastructure and the popularity of smartphones. However, the achievable throughput by such practical systems is still very low due to its availability for only low order modulation schemes and transmission frequency. In this demo, we propose a novel reflected OCC system, UniLight, which takes advantage of uniform light emission of an LED luminaire with lens to increase both region of interest (RoI) and signal-to-noise ratio (SNR) so as to improve data rate. UniLight employs a COTS LED spotlight with lens as the transmitter to uniformly illuminate a reflector so that avoids a gradual reduction of brightness from the center to both sides in the frame captured by a camera receiver. By adopting a hybrid modulation scheme for generating multi-level pulse amplitude modulation (M-PAM) symbols on the transmitter and a machine learning based demodulator on the smartphone receiver, UniLight can achieve much higher data rate than existing works with a single small-size LED spotlight.**

I. Introduction

Envisioned as an alternative to RF communications, *Visible Light Communication* (VLC) keeps attracting attentions given the increasing scarcity of RF spectrum resources. In the past decades, well-designed experimental VLC prototypes with highly sophisticated constructions have been able to deliver a throughput up to a few Gbps [1], yet none of them have been used into practice by far. At the meantime, practical *Optical Camera Communication* (OCC) systems purely built on commercial-off-the-shelf (COTS) devices have been gaining their momentum, mainly thanks to the pervasive adoption of *Light Emitting Diodes* (LEDs) lighting [2] and mobile devices (e.g., smartphones). Furthermore, OCC systems can largely eliminate interference suffered by LED-PD VLC [3], thanks to the inherent spatial division at the camera receiver [4]. Nevertheless, existing proposals are hard to deliver a sufficient data rate due to the stringent resource limits of OCC system in terms of commercial LED luminaires on the transmitter side and the low frequency response of camera receivers.

To improve the performance of OCC systems, pioneers have proposed many innovative systems [5], [6], [4], [7], [8], [9]. Earlier proposals, e.g. [5] has to use simple On-Off Keying (OOK) modulation for OCC given the low SNR under reflected light illumination, so the achievable data rate is only a few bytes per second. Recent solutions are created to boost the data rate to kbps level by switching to direct light as communication media [6], designing advanced modulation schemes [8], and applying sophisticated channel coding such as rateless codes [4]. However, the direct OCC system has already encountered its bottleneck of data rate as reported in [4], because the data rate of direct OCC is seriously relied on the dimension of the LED transmitter. The data rate of reflected OCC, on the contrary, is not directly affected by the dimension of the transmitter, so ReflexCode [7] adopting a high order modulation of Grayscale-Shift Keying (GSK) is able to achieve a much higher data rate by demodulating reflected light from three synchronized LED luminaries, but it may face problems if only one luminaire is available.

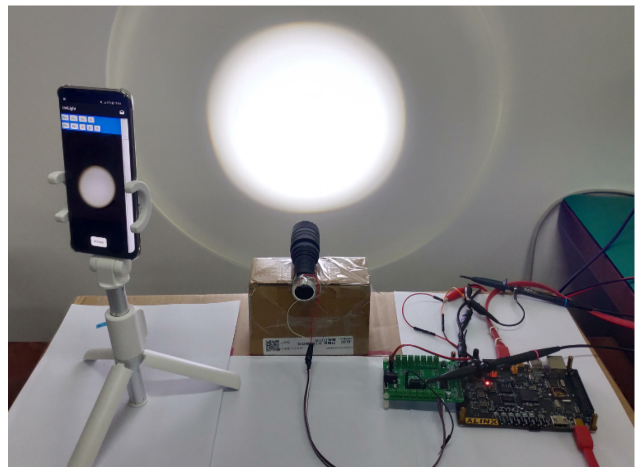

Fig. 1. The prototype of UniLight in photo.

To this end, we propose UniLight, a reflected OCC system which can support high order modulation of multi-level pulse amplitude modulation (M-PAM) with only a single LED luminaire. In particular, UniLight adopts a hybrid modulation scheme of OOK-PWM proposed in [4] to generate various brightness levels so as to represent different M-PAM symbols with one LED luminaire. Benefiting from a small lens, the modulated LED emits light to uniformly shine upon a reflector, resulting in a uniform facula on the reflector. Therefore, the UniLight's camera receiver can get a regular RoI in the frame

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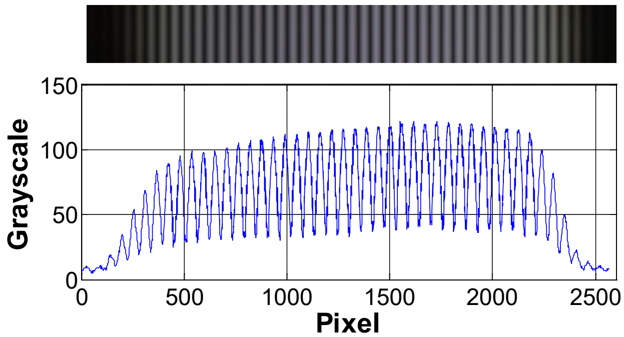

Fig. 2. Relatively uniform brightness distribution in the frame by using a spotlight with a lens.

and sufficient SNR for correctly demodulating high order M-PAM symbols as shown in Fig. 2. By using advanced machine learning based demodulator, our current UniLight can support at least 8-PAM data transmission up to a distance of 1 m. In summary, our contributions can be summarized as:

- The innovative idea of using hybrid modulation to generate M-PAM with a single LED for boosting data rate.
- A machine learning based demodulation algorithm to effectively demodulate M-PAM symbols.
- An implemented prototype for validating the effectiveness of UniLight, and the experiments to show its promising performance.

The remainder of this demo is organized as follows. We first present the system architecture of UniLight in Section II. Section III presents the facilities requirements, and Section IV quickly concludes this demo.

II. System Architecture and Implementation

The system is partitioned by default into two parts, namely transmitter and receiver. As shown in Fig 1, the transmitter consists of a COTS LED luminaire with a lens, while the receiver uses a smartphone camera as its front-end. Although the reflector is part of the communication media in UniLight, we omit to design it yet prefer white reflectors such as a white wall. On the transmitter side, M-PAM symbols are generated by inserting pulse width modulation (PWM) waves with different duty-cycle at a high frequency of 200 kHz which can not be sampled by the rolling-shutter camera, and detailed description can be found in Section 3.5 of [4]. So the single LED can transmit M-PAM symbols with only digital control signals, while the existing relfected OCC system of ReflexCode needs three LEDs [7]. On the receiver side, demodulation is proceeded by a machine learning based classifier which can dynamically adapt to the changing environments. Moreover, the classifier also plays the role as a equalizer to eliminate ISI, which further improve the system performance by supporting higher transmission frequency at the same bit error rate.

We build a small-scale prototype using a COTS LED spotlights with lens [10]. This prototype is meant to emulate the reflected lighting [11], as the spotlight is facing directly to the reflector (a billboard). In our current UniLight prototype, the distance between the LED spotlight and the reflector is around 50 cm. We implement the LED driver with low-cost transistors and an Xlinx FPGA processor for driving the LED light with modulated signals. The prototype runs at a transmission frequency of 5kHz for M-PAM symbol stream and a frequency of 200 kHz for PWM waves. We employ a Samsung S8 smartphone as the receiver, and build an APP on it for demodulation/decoding. Basically, we configure the smartphone camera to work in the preview mode to capture banded frames at a rate of 30fps. Our video demo can be found via the hyperlink of [12].

III. Facility Requirements

In this demonstration, we will setup the UniLight prototype with a spotlight. We will bring our LED spotlights, own laptops and smartphones, but we do need a desk as well as power outlets. Specifically, we need a plain panel (wall) perfecting in white or light color, and the available area should not be less than $0.6m \times 0.6m$ above the desk. Our demonstration does not require special Internet access, yet the Wi-Fi connection might be required. The whole setup process should be less than half or an hour.

IV. Conclusion

In this demo, we have presented UniLight, a novel yet practical reflected OCC system that adopts a spotlight with a lens to transmit high order M-PAM symbols. Compared with the existing peers, UniLight has improved on throughput substantially, mainly due to its innovation on using uniform light. This demo will first showcase UniLight for public and demonstrate its promising performance.

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